



NRC-CMRC

Aerospace

NRC CT-133 ACCESS II DATA ANALYSIS:- GASEOUS, AEROSOL AND CONTRAIL CHARACTERISTICS

A P Brown, Matthew Bastian, Mike Pryor, Per Talgoy,
Flight Research Laboratory, NRC

IFAR

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National Research
Council Canada

Conseil national
de recherches Canada

Canada 

Acknowledgements:-

NASA ACCESS II was notable in technical content and international collaboration. The support of Transport Canada (TC) under the TC Clean Transportation Initiative for National Research Council Canada (NRC) participation, is acknowledged and appreciated.

NRC CT-133 ACCESS II FLIGHT DATA PRESENTATION:-

DESCRIPTION

NRC CT-133 research aircraft

CT-133 research flights:-

- pre- & post-ACCESS contrail flights (April, June, Oct, Dec)
- ACCESS-II: against DC8, 3 x low sulphur JetA/HEFA, 1x med.S Jet A; 2 x FA20 (DLR), HU-25 (NASA)

Flight profiles

RESULTS & DISCUSSION

Wake vortex dynamics

Gaseous emissions

NO_y

CO₂

water vapour (discussed under contrail characteristics)

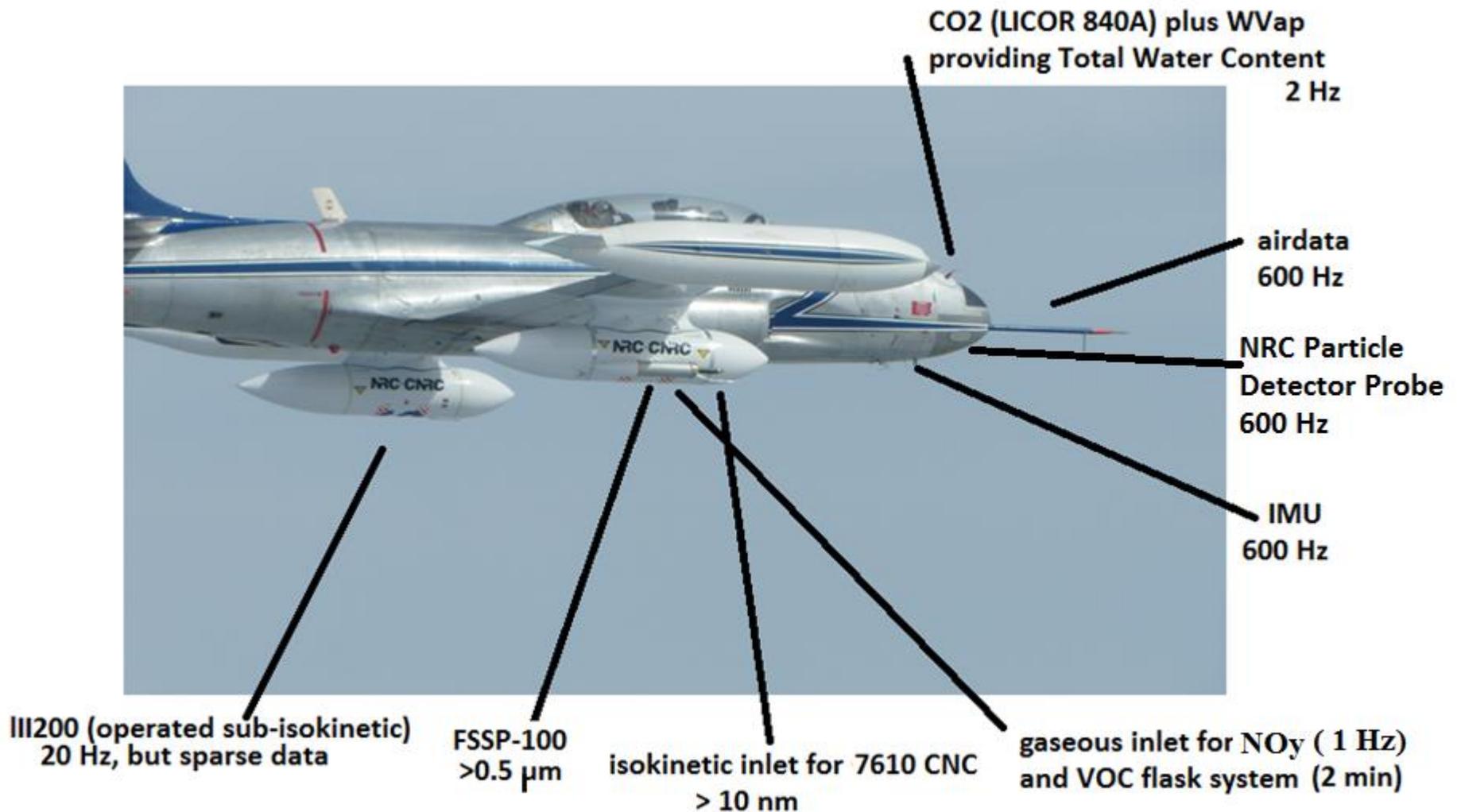
Particulate emissions, aerosols, >10nm

Contrail characteristics: ice particle number, mass; water vapour

EI_{ICE} & EI_w ; parameterisation of EI data-set

CONCLUSIONS

NRC CT-133 RESEARCH AEROPLANE, for EMISSIONS



**4-engine emissions, 1-15 nm length:-
DC8 at M0.8, 4 x thrust for level flight**

**NRC CT-133 ACCESS II
FLIGHT PROFILES
(contrail conditions)**



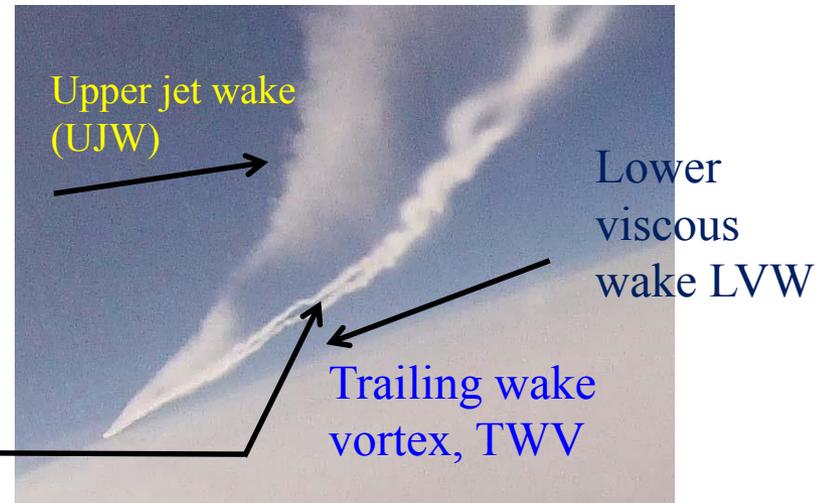
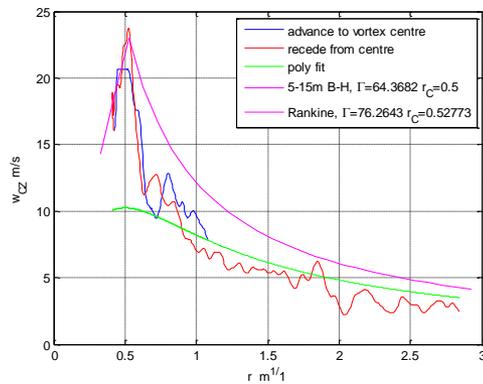
**1-engine (inboard)
emissions, 0.2-3 km
length:-
DC8 at M0.52, level
flight**



***DC8 on ACCESS M0.8 cruise contrail field:- 1/2 to 1 1/2 nm UJW
contrail; 10-15 nm vortex contrail***



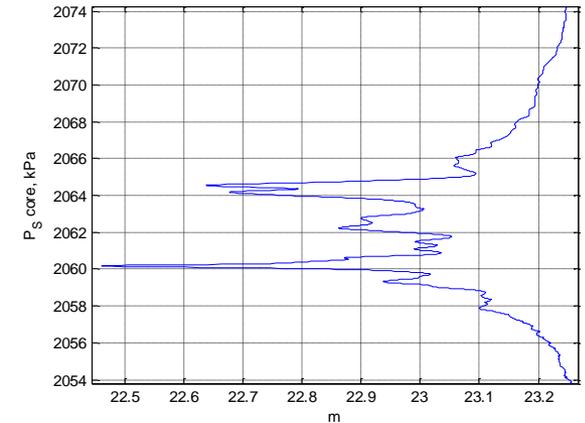
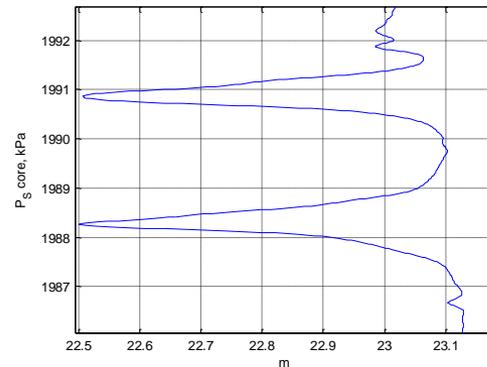
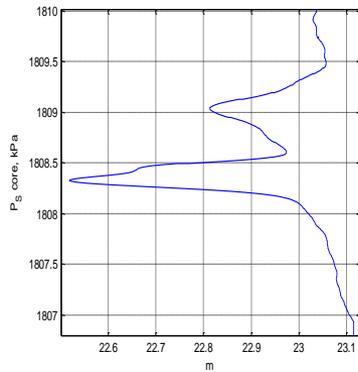
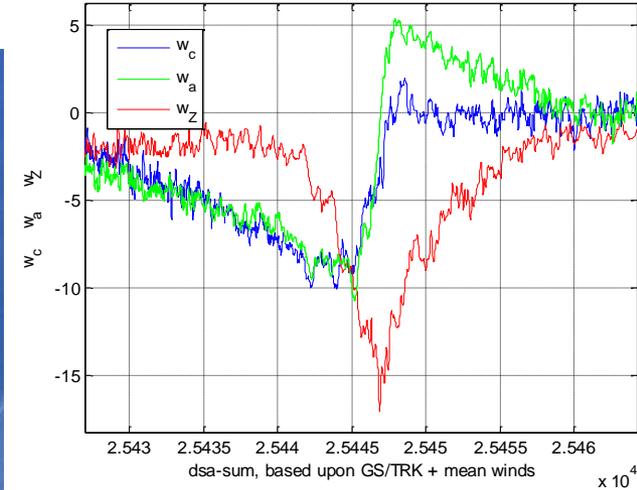
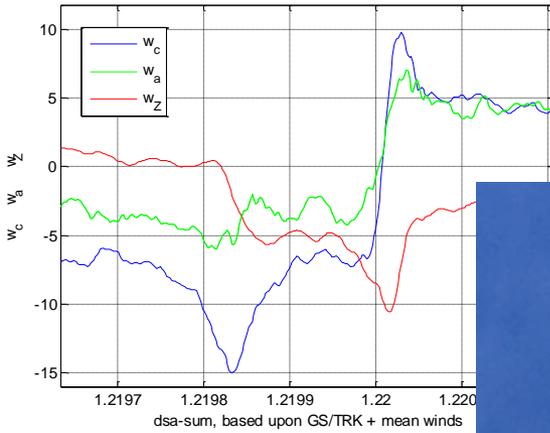
***c.f. NRC Aviation Environmental
Emissions Measurement
(AEEM):-
B744***



DC-8 trailing wake vortex characteristics, r_C & V_T :-

– r_C , *small vortex cores*, 0.5 to 2m radius

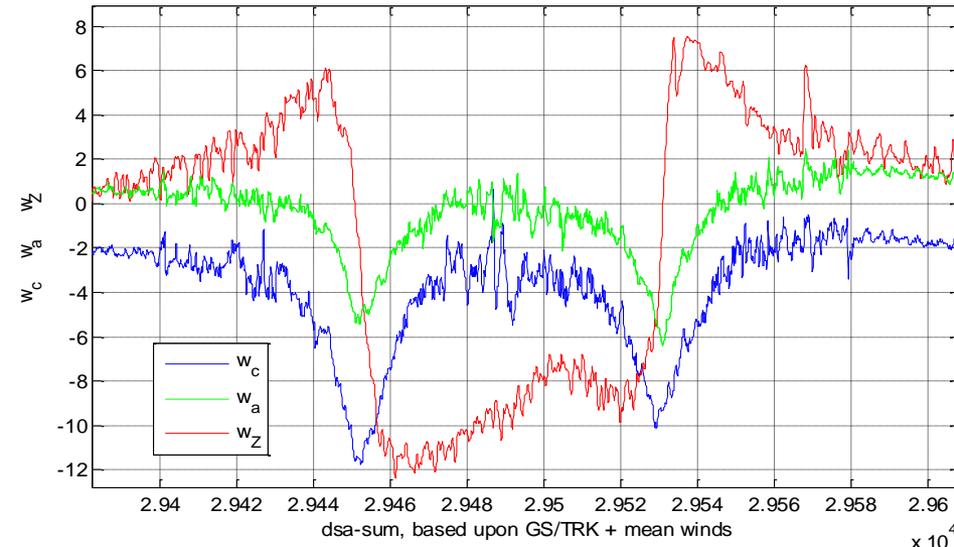
– V_T , 15-70 m/s (circumferential vortex elements)



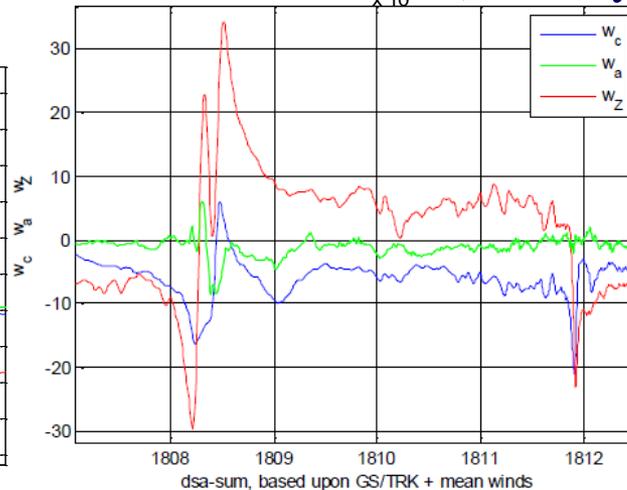
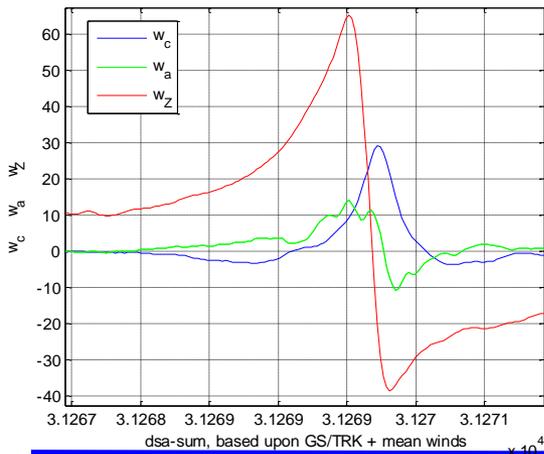
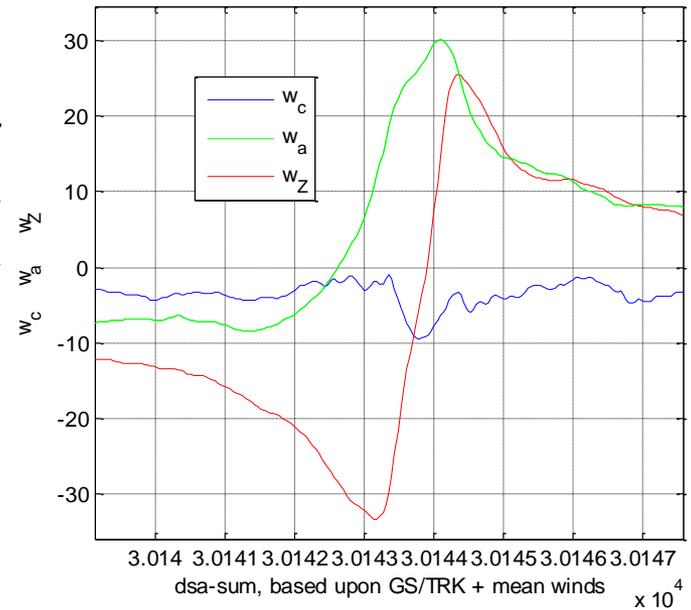
Trailing wake vortex characteristics, r_C & V_T :-

– LEFT, large r_C & large separation (possibly local, long-wave instability, excited by cross-track vorticity

– BELOW, small r_C



annular
core
State
(non-
steady)



– **unusually strong axial velocity characterisation**

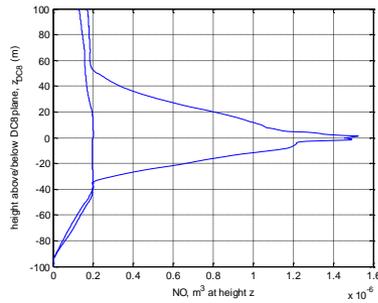
DC-8, trailing wake vortex, strong influence on emissions:-

- Characterising the NASA DC-8 wake vortices, M0.8 crz
 - short wave, elliptical instability – funnels (core radius changes, r_c 0.5 to 2m)
 - Typical core venting – annular vorticity cores
 - High velocity peaks (c.70 m/s);
 - atypically *strong* axial flows (c.40 m/s)
 - mild long-wave instab., linking at 15 nm on 10th May flight
 - Large descent distance, 800-1000 ft
 - no significant tertiary structures (e.g. helical vorticity)
 - atypical close-spacing, b_v 62-65% geometric span
 - Greater entrainment => negligible Upper Jet Wake (B763,A388 etc)
 - climb, 1-5 nm length (15-40 sec, $t^*=0.2-1$); cruise 1-16 nm
-

GASEOUS EMISSIONS:-

1. NO_y
2. CO₂
3. Water Vapour (will be discussed under contrail ice characteristics)

NO_y PLUME CROSS-SECTIONAL PROFILES:-

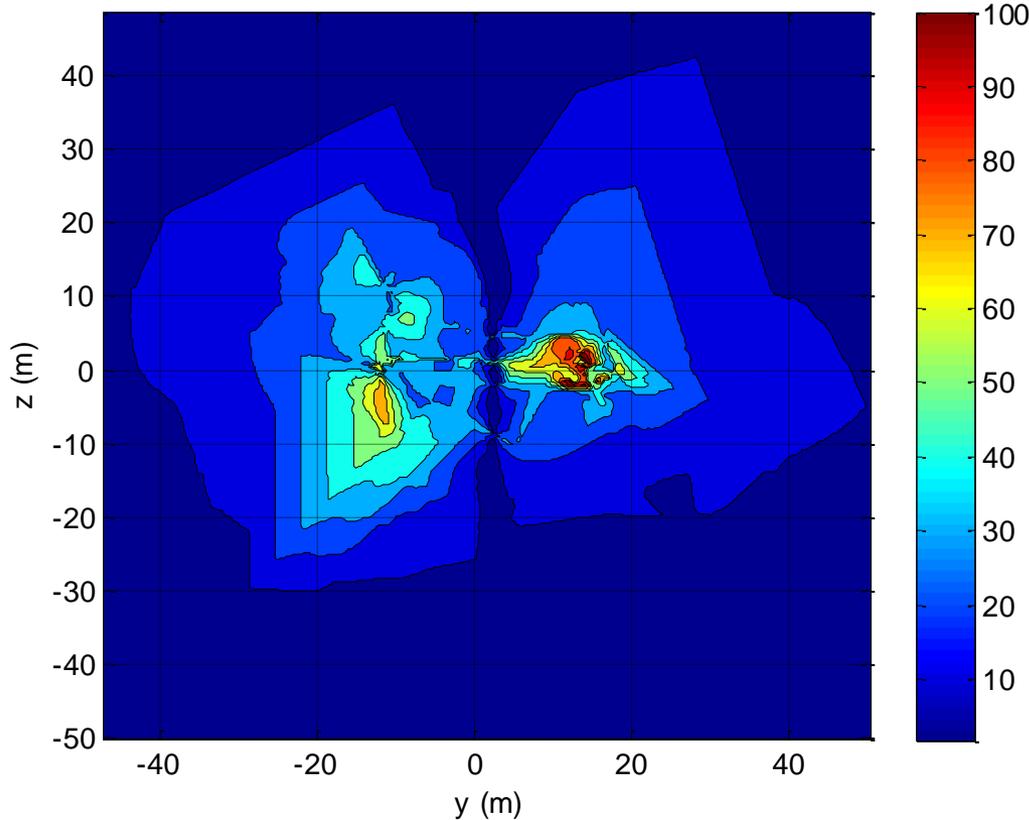


LEFT – 4-engine, M0.8, TFLF (climb thrust at 35,000 ft)

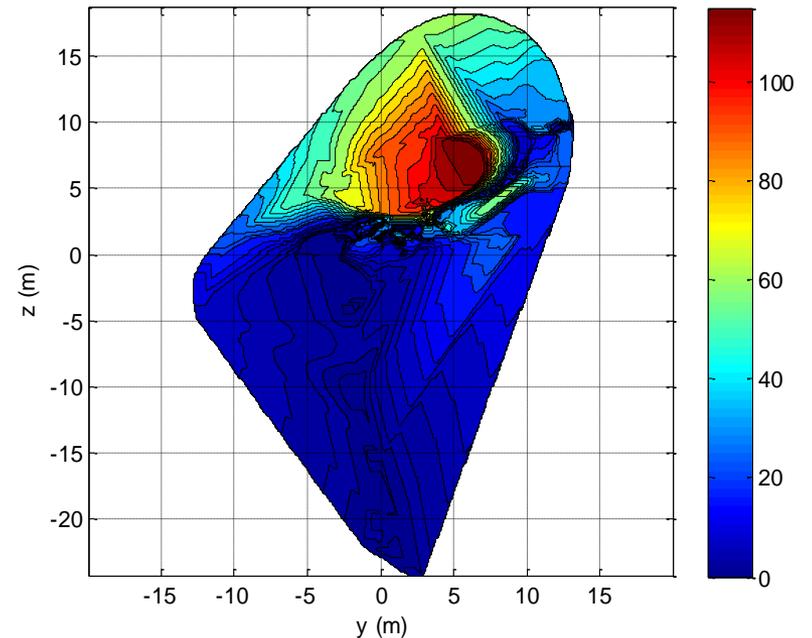
BELOW, I/B engine plume

- Spatially integrate => NO_y EI

DC8 wake NO & HONO concentrations, ppb, 5.0-15 nm wake length



DC8 wake NO & HONO concentrations, ppb, 0.05-0.5 nm wake length

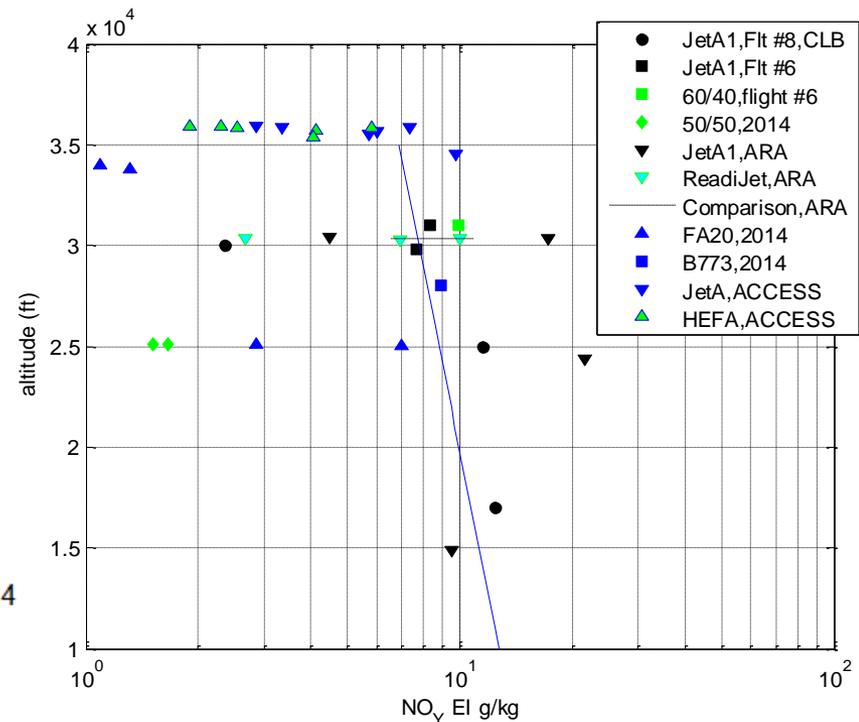
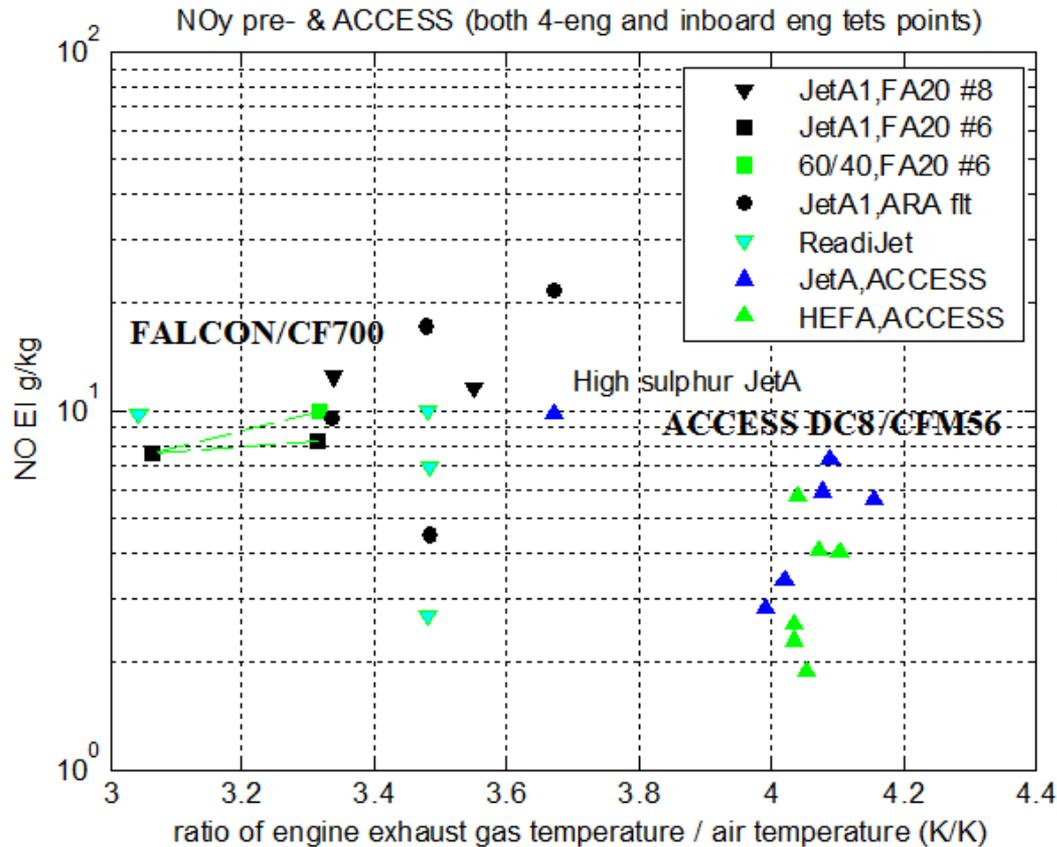


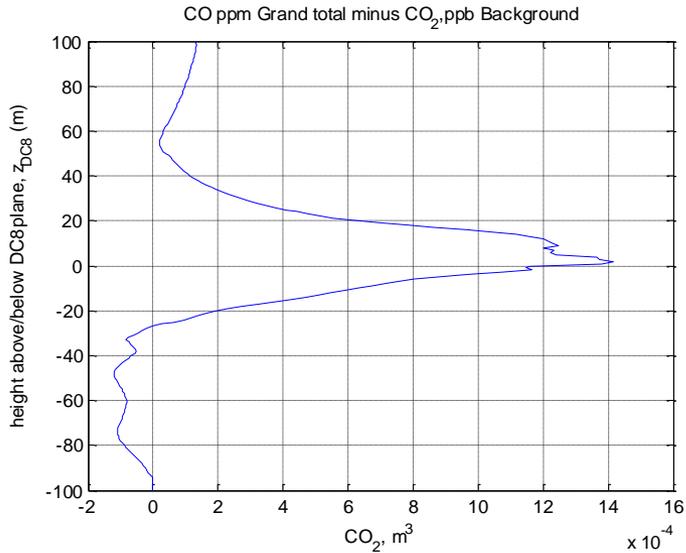
NO_y (1 Hz streaming) EI SUMMARY:-

NO_y EI expressed, using a non-std MW of 30 (EI ranges 3-20 g/kg), LEFT, plotted against engine gas temperature, BELOW, plotted against altitude

Preliminary

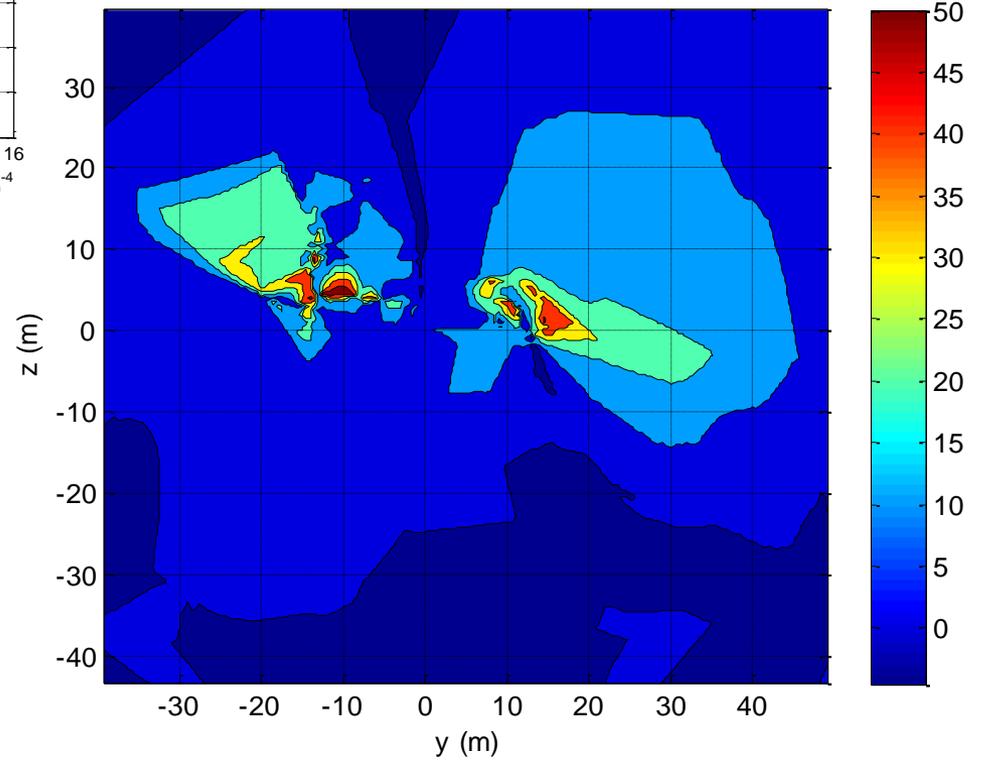
For ACCESS DC8/CFM56, and earlier NRC Falcon/CF700



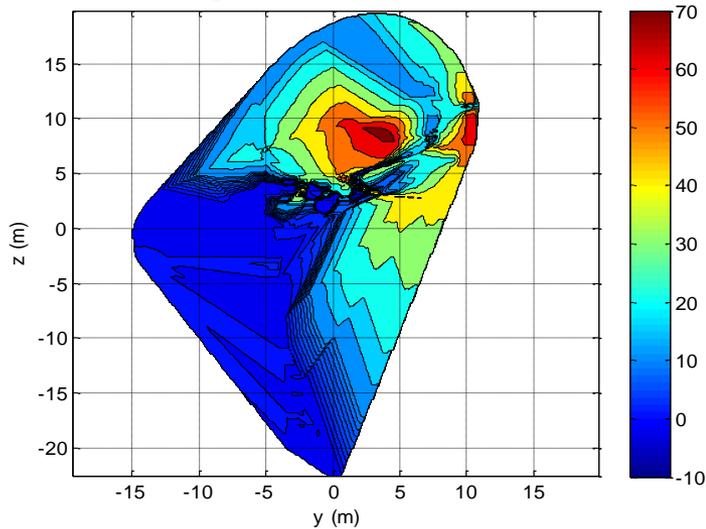


CO₂ CHARACTERISTICS, CRUISE, 11km, M0.8, Low-sulphur CO₂:-

DC8 wake CO₂ concentrations, ppb, 9-25 nm wake length



DC8 wake CO₂ concentrations, ppb, 9-25 nm wake length



Over-estimates EIm_CO_trav = 4.1902 kg/kg

9th May, CRUISE, 11km, M0.8, 50%

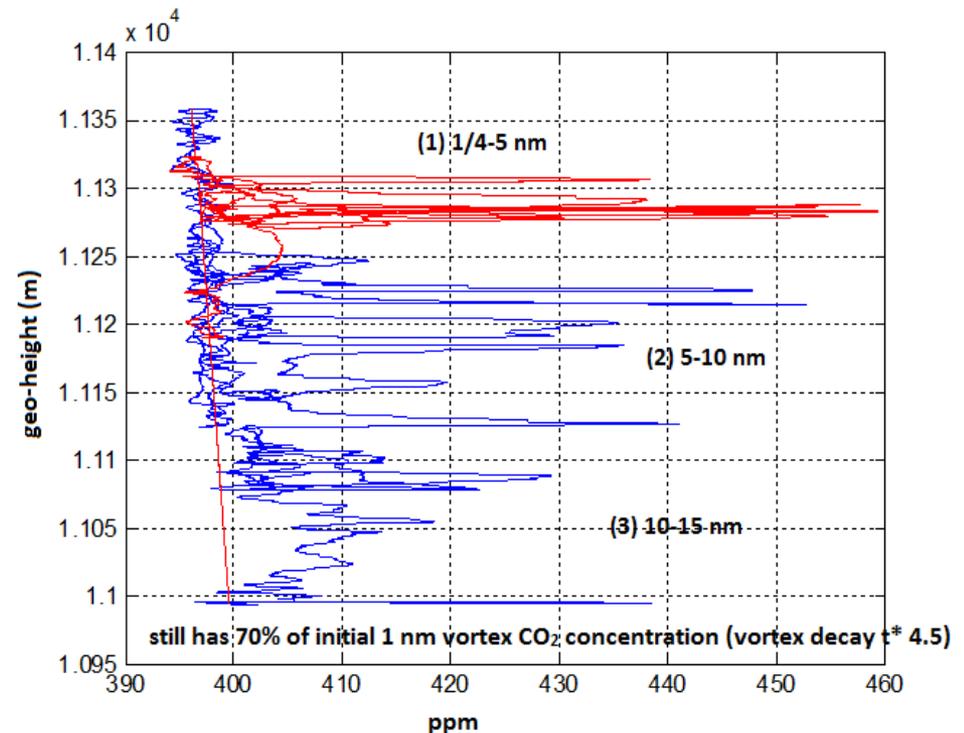
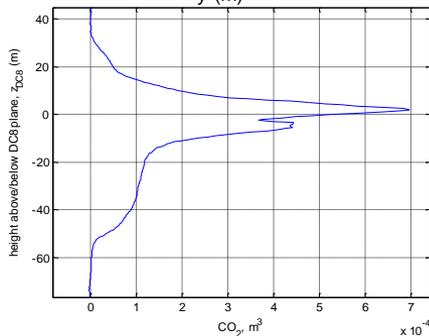
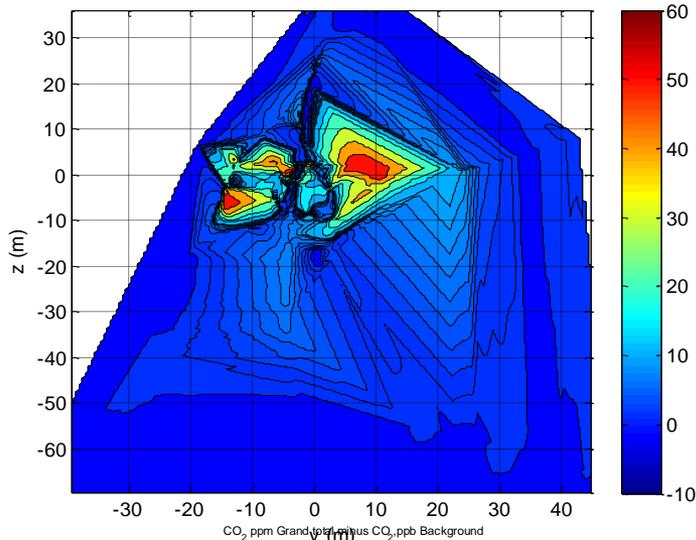
HEFA:-

1/4-5 nm
Elm_CO2 = 2.9357

– CO₂ plume

- NOTE:- direct integration to give CO₂ EI
 - LEFT, 1/2-5nm, 4-engine plume
 - BELOW, retention of peak CO₂ concentrations in vortices

DC8 wake CO₂ concentrations, ppb, 9-25 nm wake length

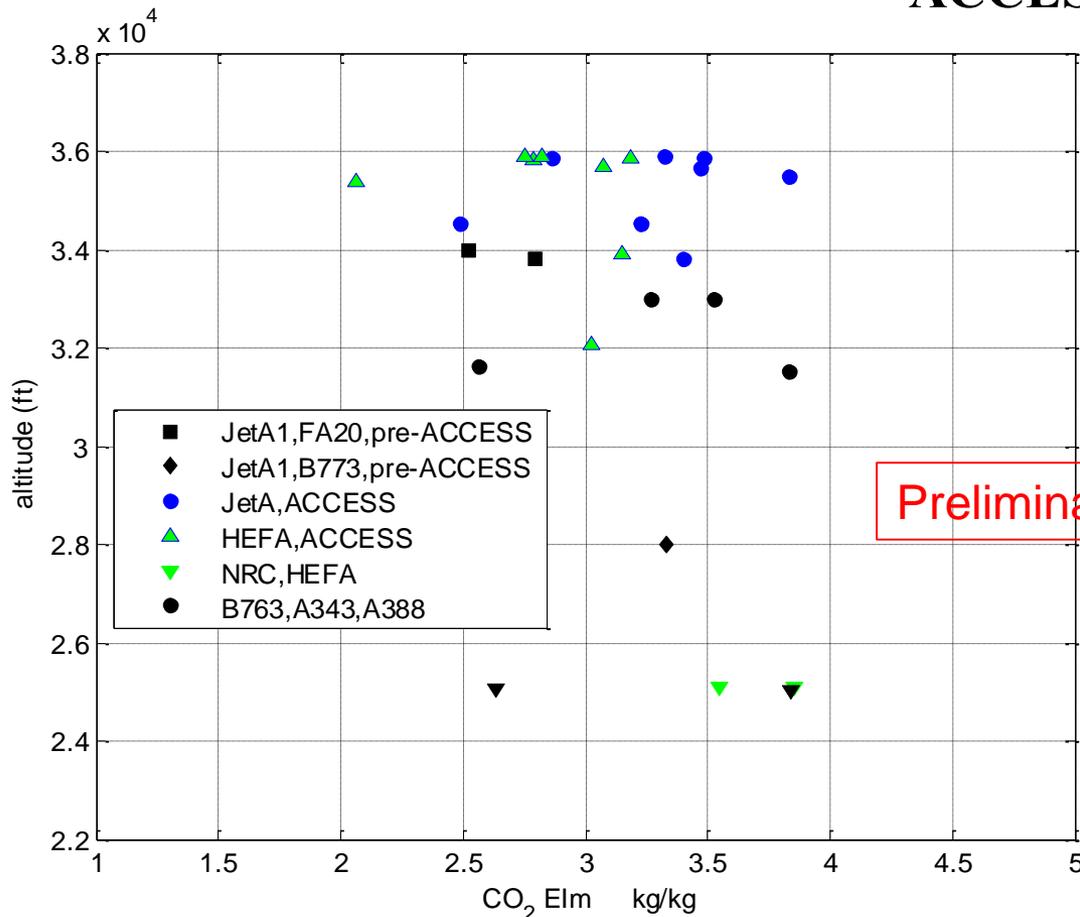


CO₂ EI SUMMARY:-

Stand-alone derivation of CO₂ EI, by integration of holistic emissions plume, whether 4-eng or 1-eng

ACCESS II, JetA and HEFA combined

mean CO₂ EI 3.26 kg/kg
(within 5% of nom.3.1 kg/kg)
with data-set $\sigma = 0.42$ kg/kg

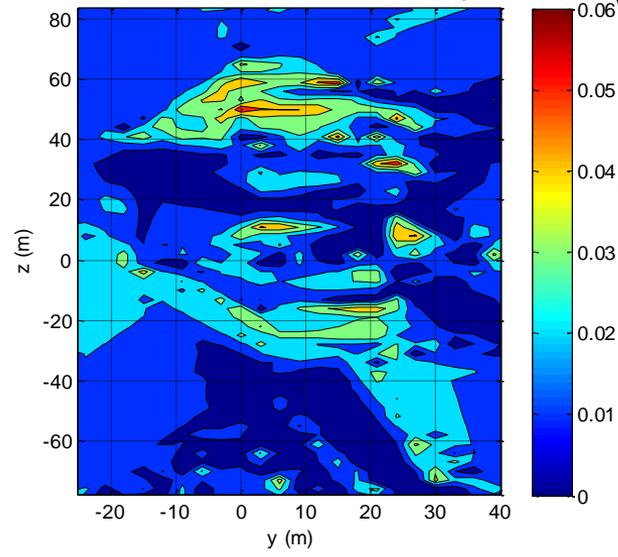


Preliminary

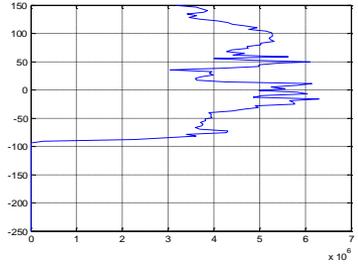
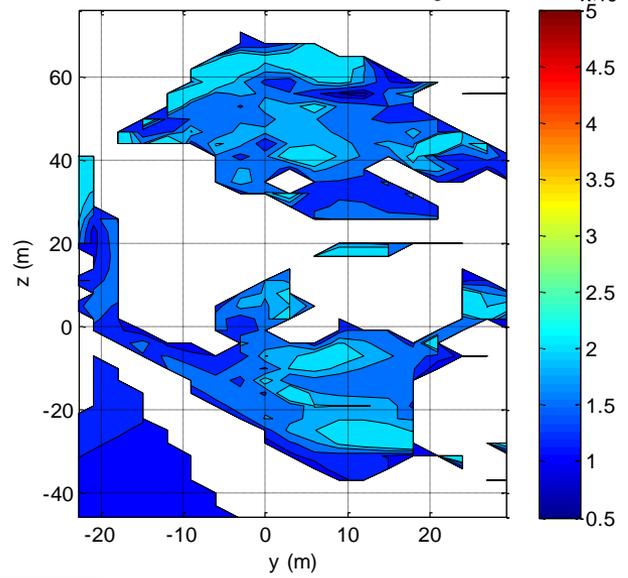
AEROSOL EMISSIONS:-

- 1. Climb M0.5, UJW, TWV, LVW
- 2. Cruise, M0.8 – TWV regime dominates, as for gaseous & contrail species

DC8 wake FSSP concentrations, no./cm³, short wake length 5.5-17 nm nm



DC8 wake FSSP Mean Diameter, short wake length 5.5-17 nm nm $\times 10^{-6}$



CRUISE, 11km height, M0.8, Low-sulphur 1-15nm length plume re-construction:-

EIn_CN_trav = 6.4265e+14

– Height is trailing vortices-referenced

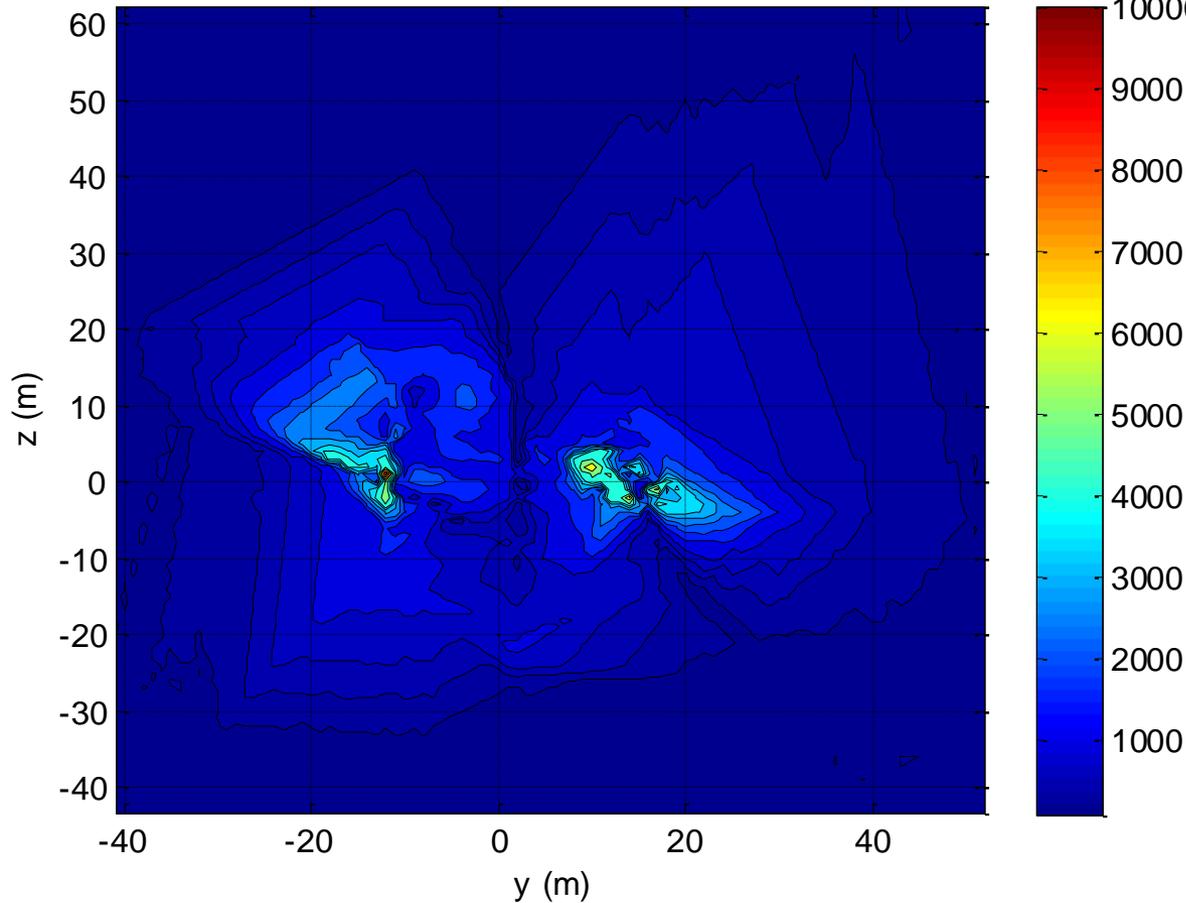
Absence of an Upper Jet Wake (UJW)

– Thus, lack of contrail cirrus

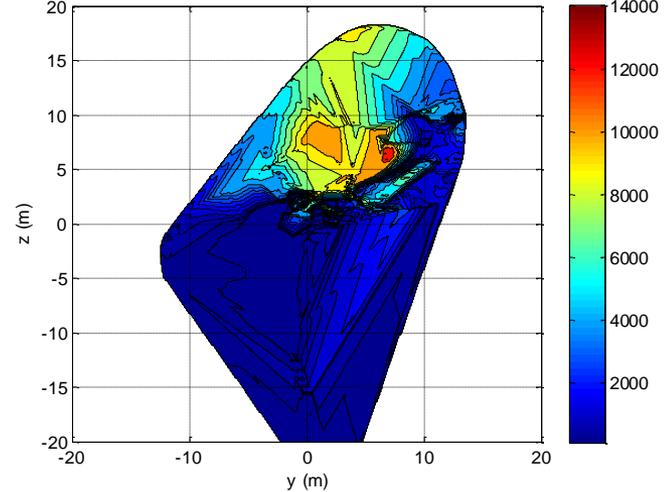
– Implications of aircraft design

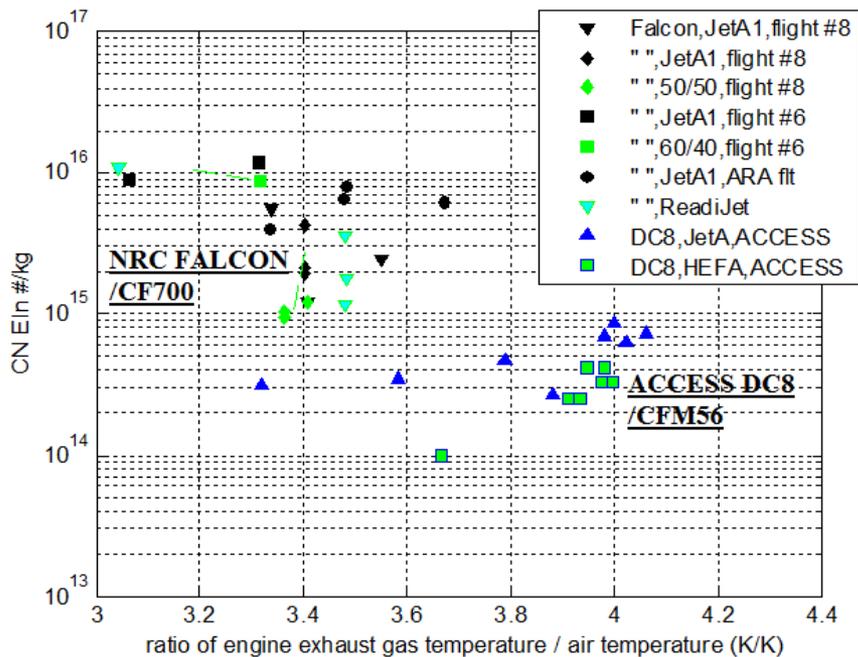
– BELOW, engine no.3 at 200 m

DC8 wake CN concentrations, no./cm³, short wake length 5.5-17 nm nm)



DC8 wake CN concentrations, no./cm³, short wake length 5.0-15 nm nm)

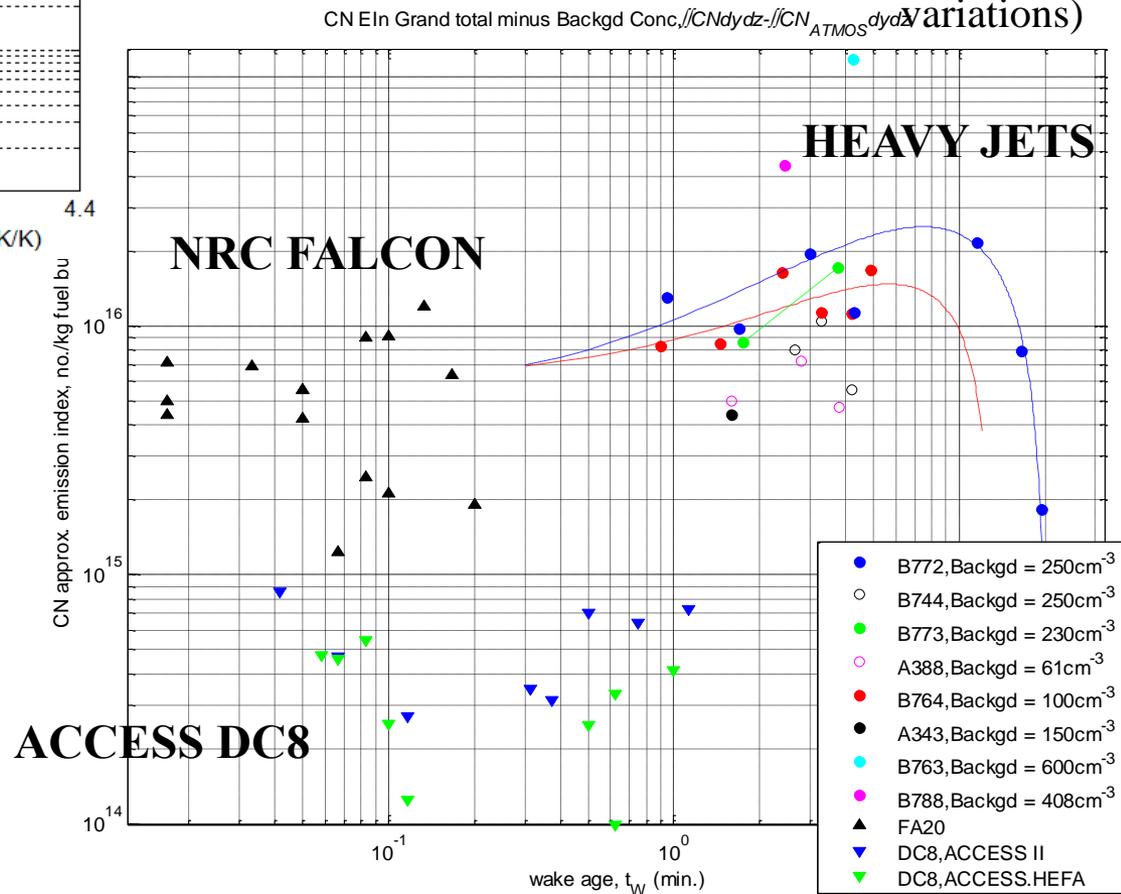




Preliminary

CN Ein SUMMARY:-

Contains both 4-eng, M0.8 holistic plumes, & 1-eng (I/B), M0.5 plumes. All low-sulphur JetA
 For ACCESS II data, $\Delta CN_{Ein} -57\%$ with $\sigma < 13\%$ (i.e. includes physical effects, altitude & thrust-setting variations)



CONTRAIL CHARACTERISTICS:-

Ice & water vapour

Cruise, M0.8

'Holding', M0.5

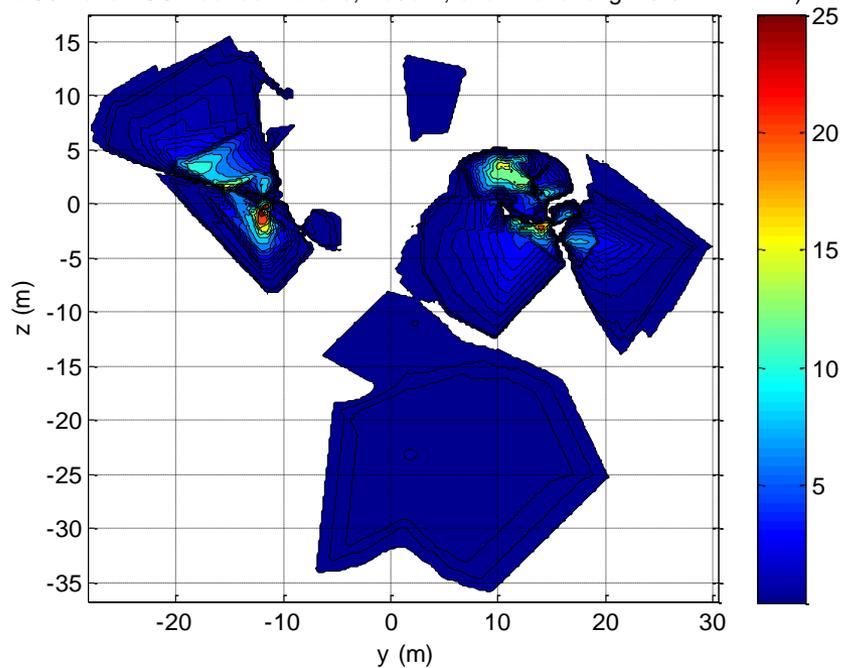
1. 4-eng

2. 1-eng

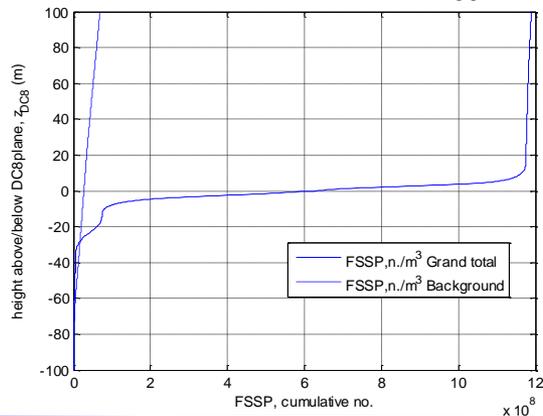
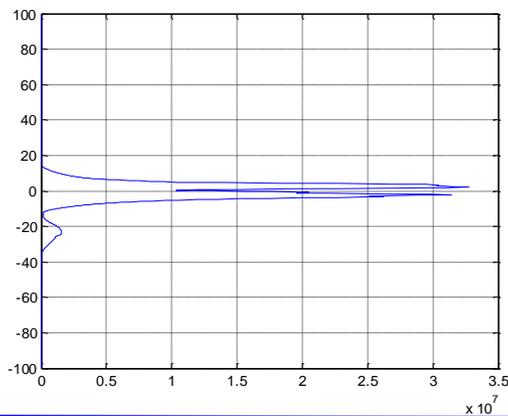
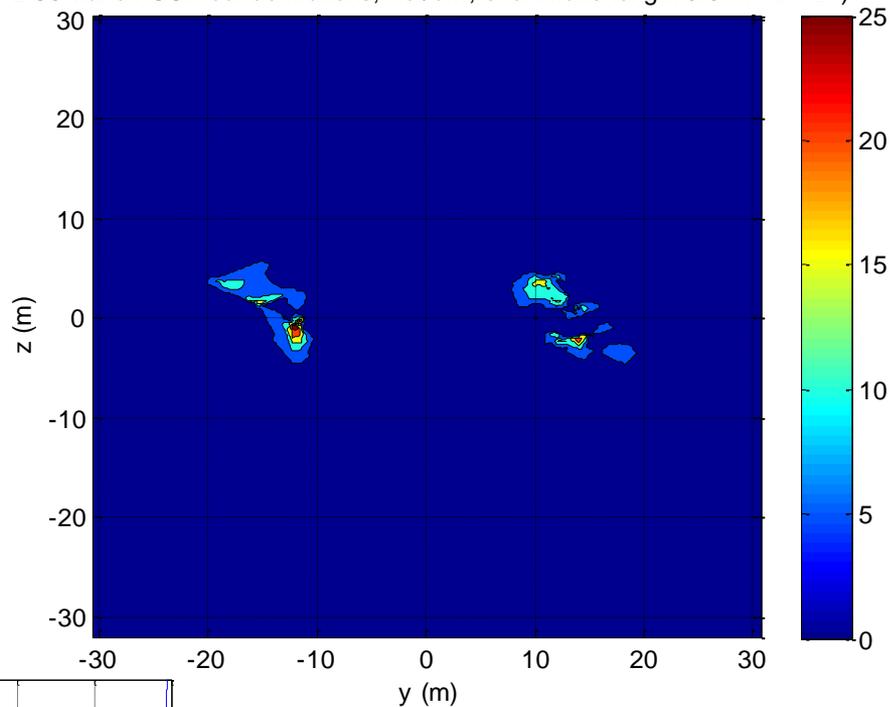
CRUISE, 11km, M0.8, Low-sulphur

FSSP-100 ($\geq 0.5\mu\text{m}$):-

DC8 wake FSSP concentrations, no./cm³, short wake length 5.5-17 nm nm)

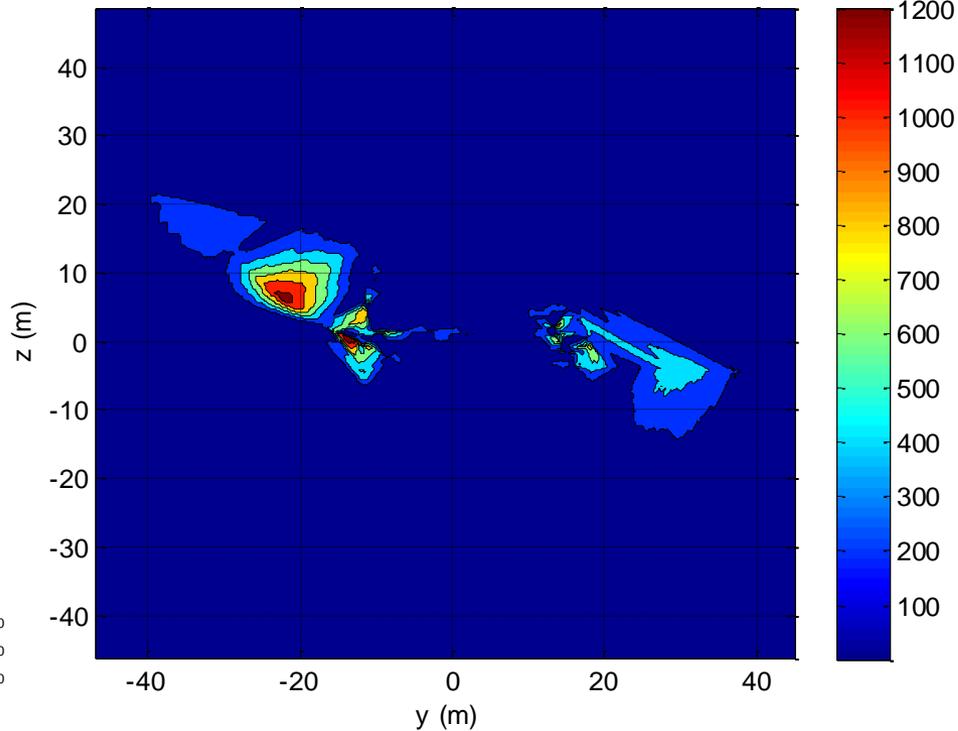


DC8 wake FSSP concentrations, no./cm³, short wake length 5.5-17 nm nm)

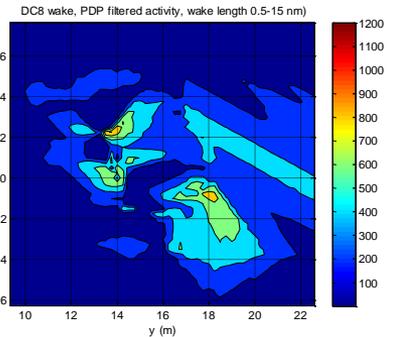
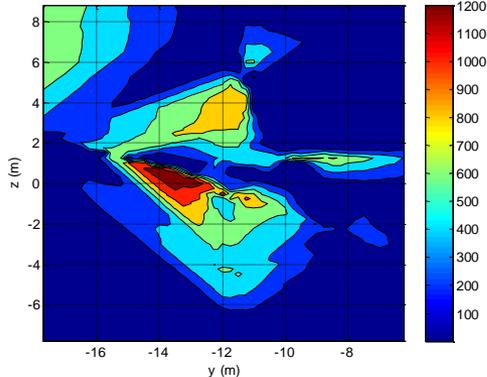


CRUISE, 11km, M0.8, Low-sulphur:- NRC PDP output signal (excellent for bulk ice particles (no sizing); negligible for solid particles) :-

DC8 wake, PDP filtered activity, wake length 0.5-15 nm



DC8 wake, PDP filtered activity, wake length 0.5-15 nm

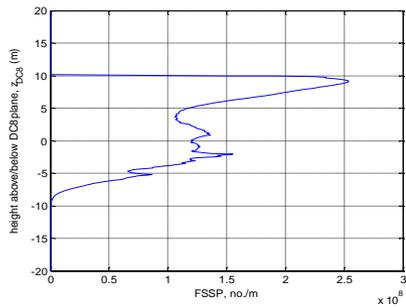


PORT vortex core sizing STBD

DC-8, I/B engine contrail sampling:-

- Distance, nom. 200 m to 3000 m

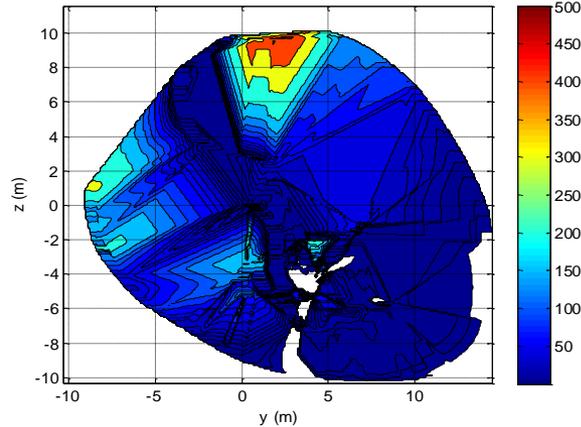




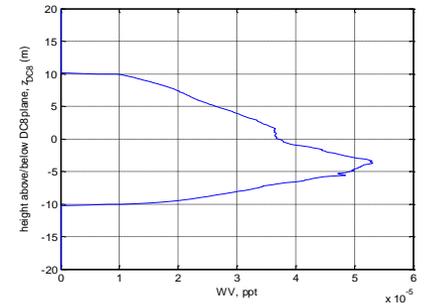
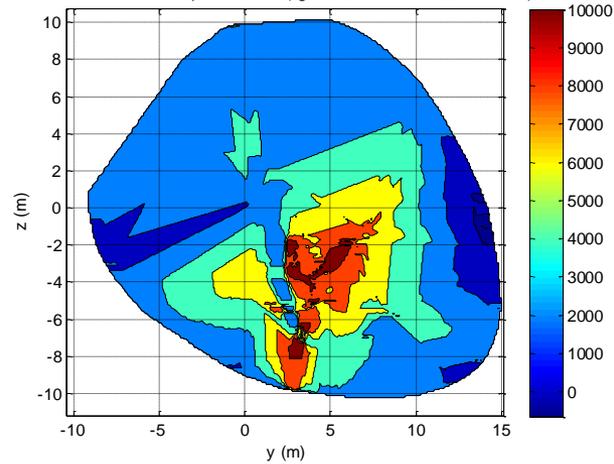
I/B engine, 8th May:-

- FSSP-100 & LICOR 840A – data complementation
- Also, validated cross-sectional plume re-construction (as different probe positions)

DC8 wake FSSP concentrations, no./cm³, short wake length 5.0-15 nm nm

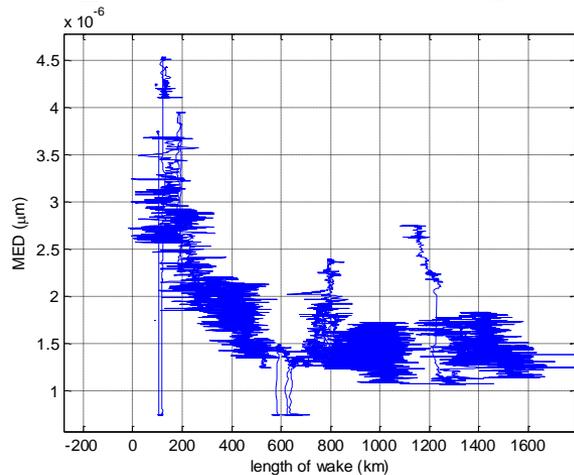


DC8 wake Water Vapour m,ment, µg/m³, short wake 0.05-1 nm nm



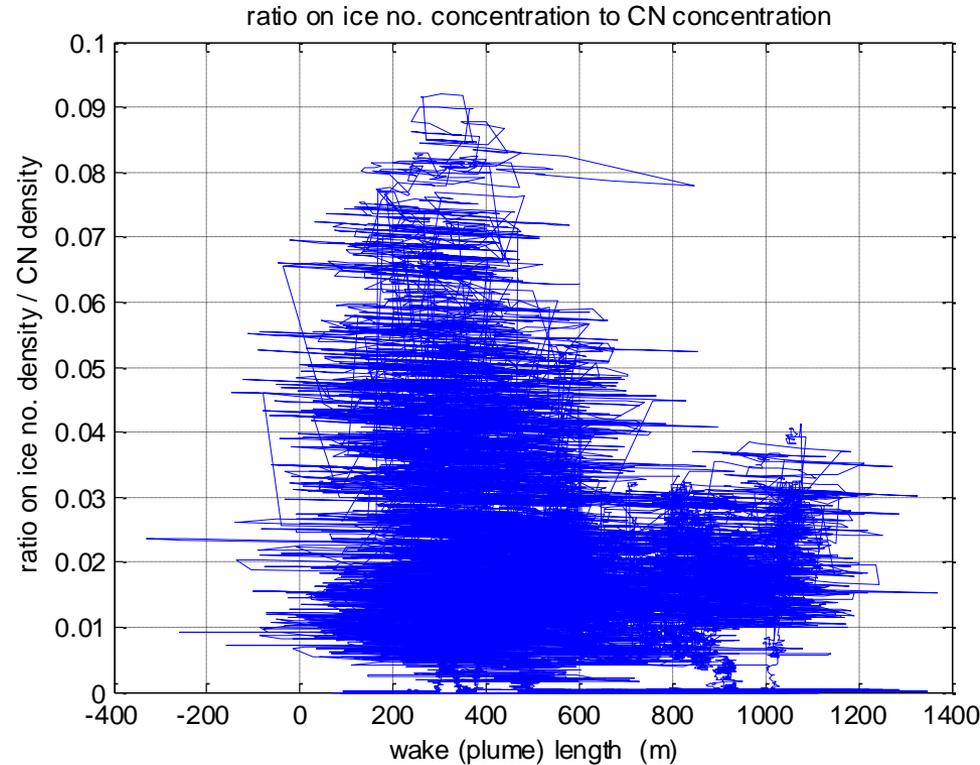
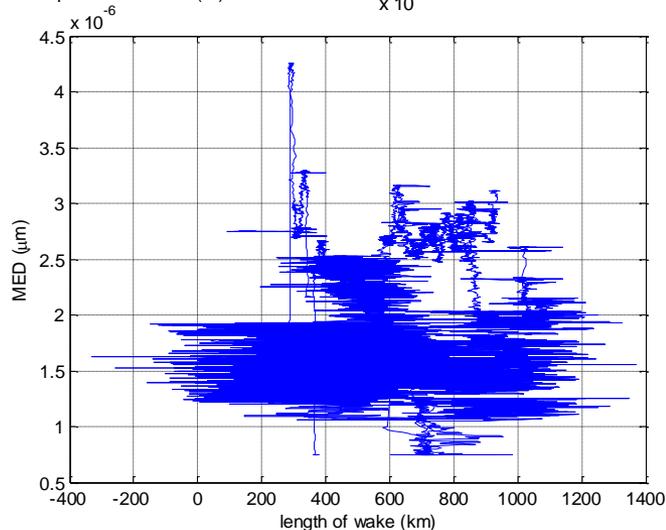
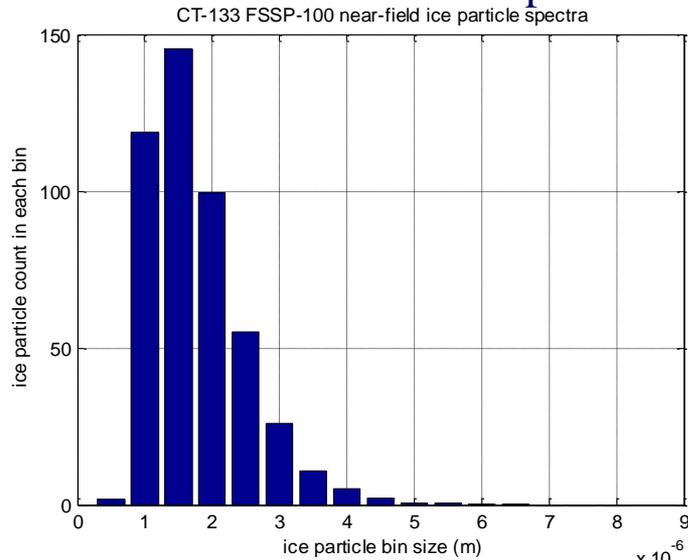
$EIn_FSSP_trav = 1.1761e+13 \text{ \#}/kg$

$EIm_H2O_trav = 7.7412e+08 \text{ \mu g}/kg$



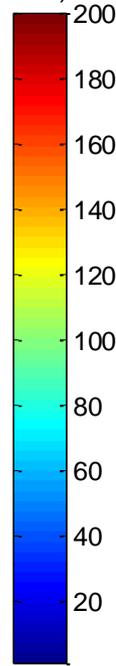
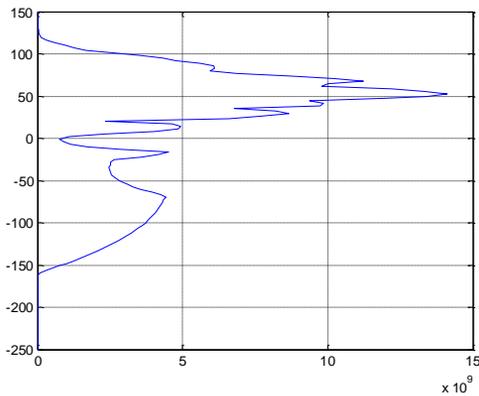
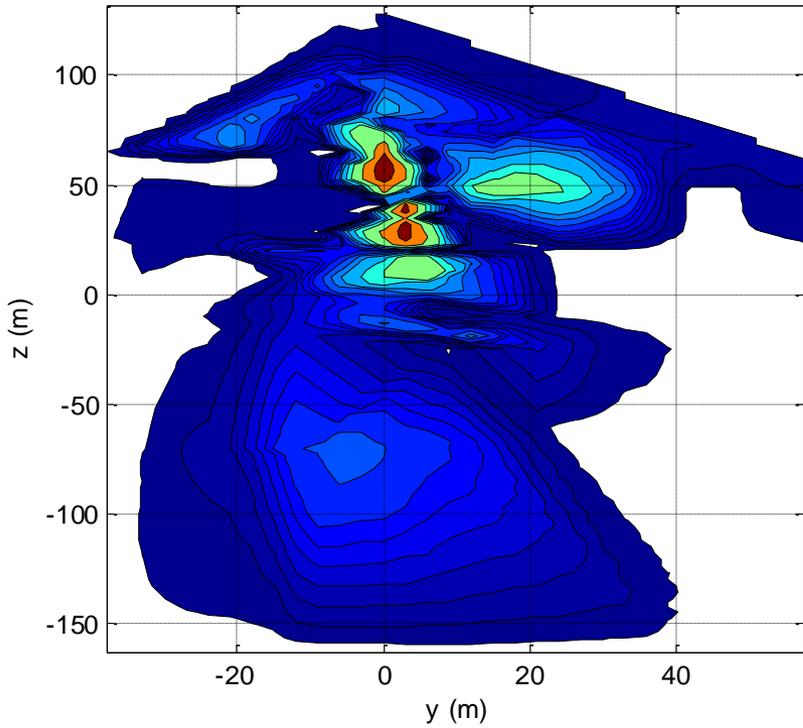
ANOTHER CASE:- I/B engine, 8th May, JetA:-

- FSSP-100 ice particle count & close-downstream development, spectrum (left) at 428 m (10 b), median size (left below), ratio of N conc to CN conc (right)



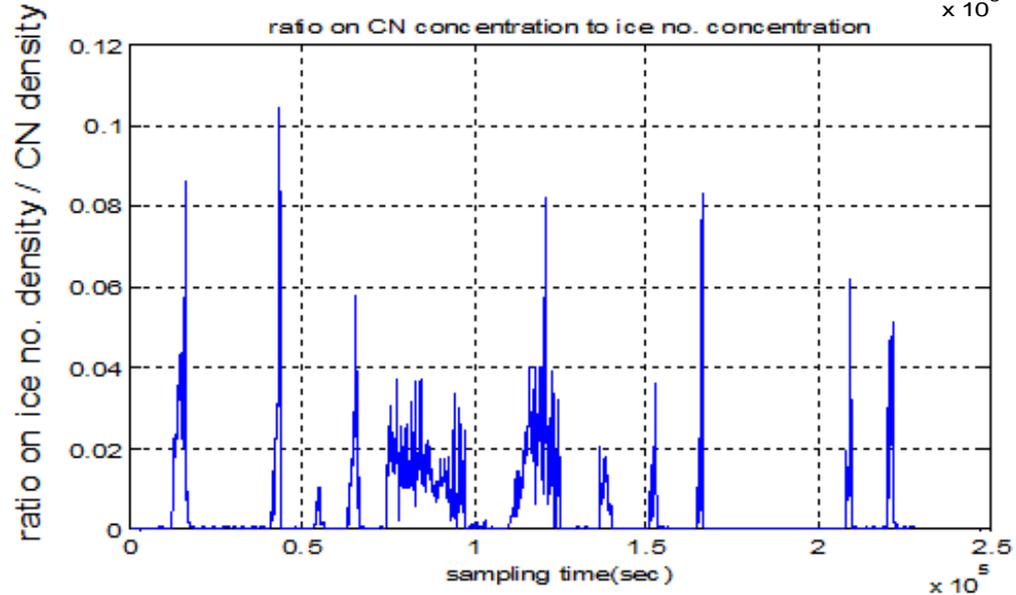
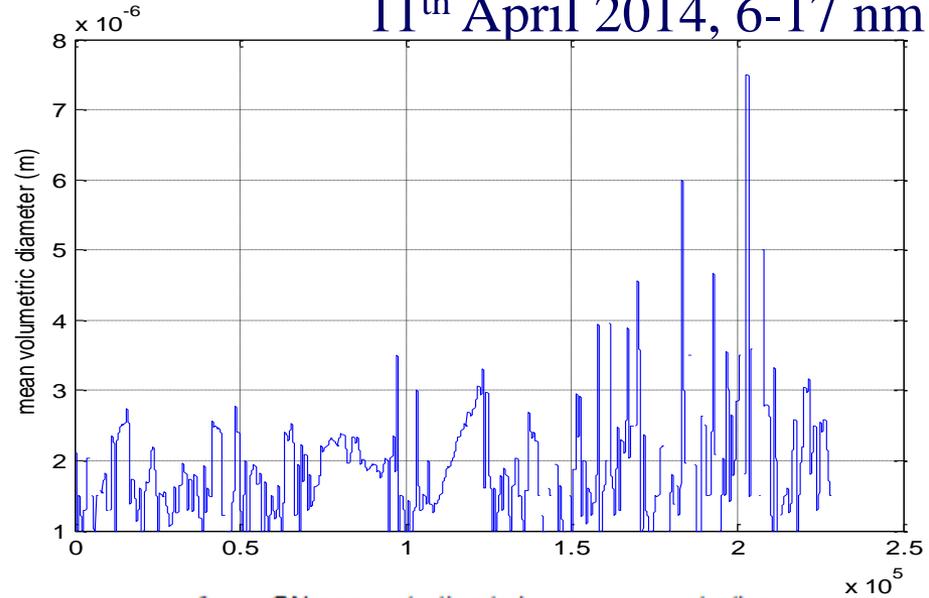
i.e., sublimating over the length range
Of 0.2-2 km, unlike a persistent pre-
ACCESS B773 contrail (N of Ottawa):-

B773 wake FSSP concentrations, no./cm³, short wake length 5.5-17 nm



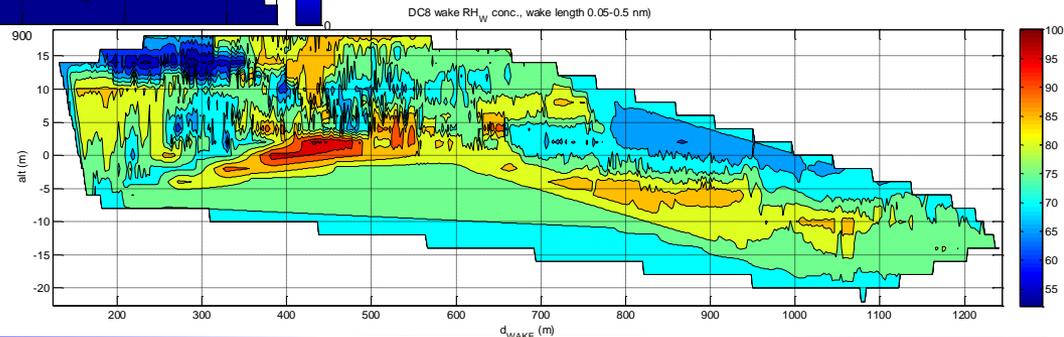
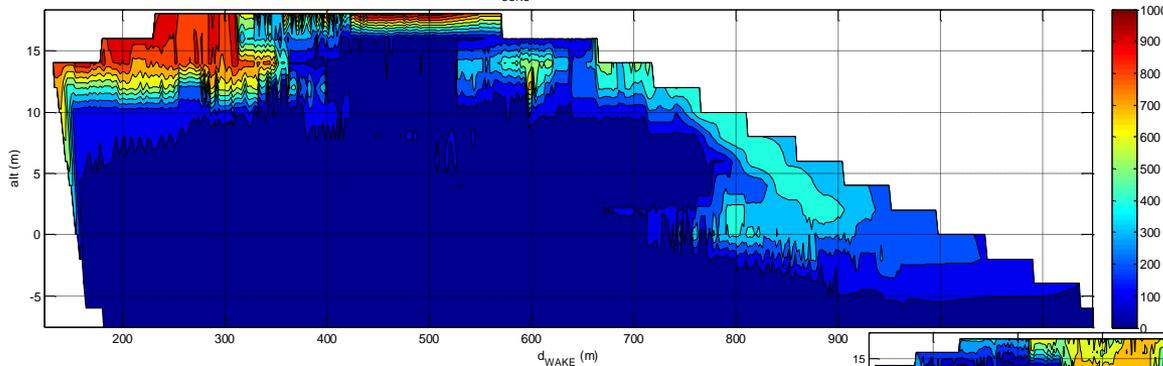
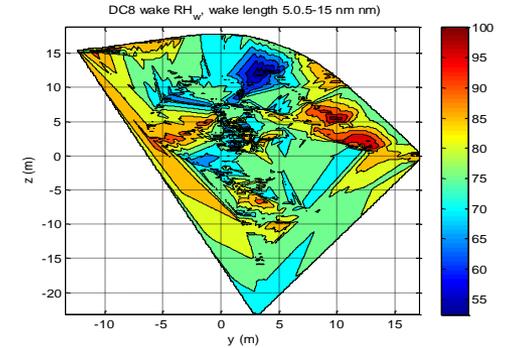
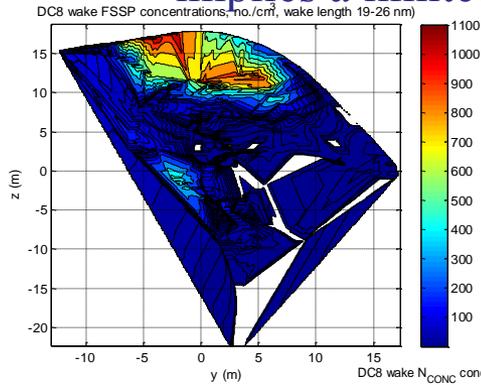
B773 contrail, N of Ottawa:-

11th April 2014, 6-17 nm



Water vapour measured:-

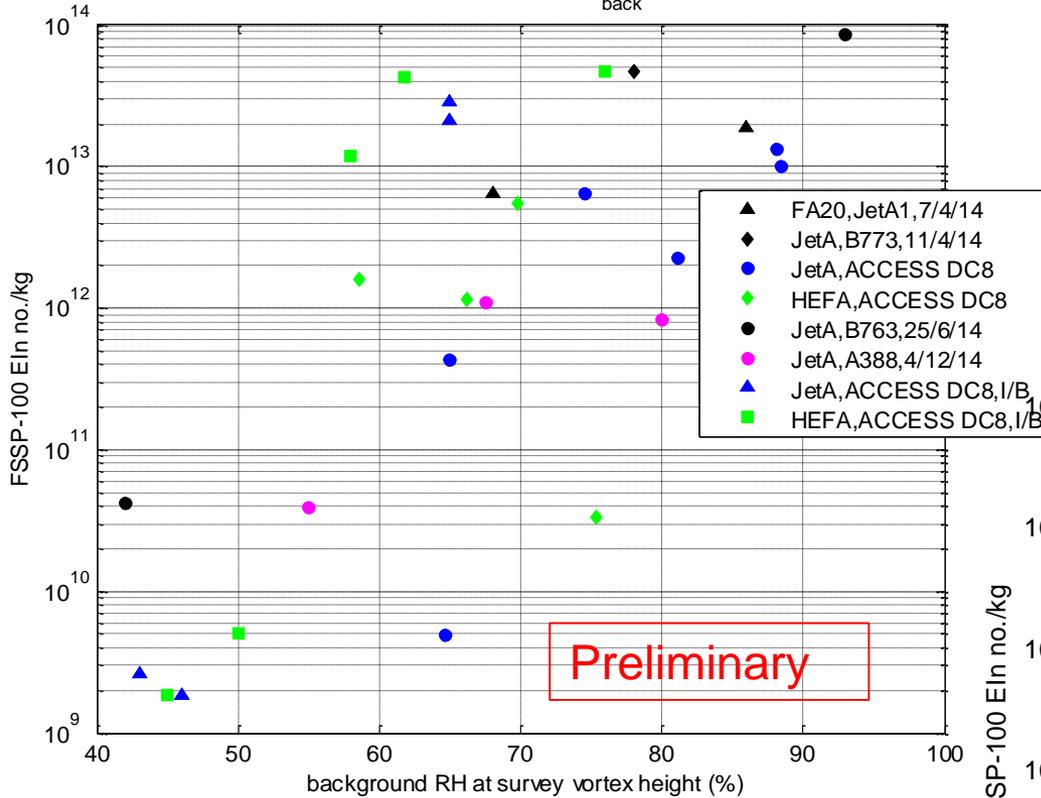
- the measured plumes from the FSSP-100 & the LICOR 840A comparatively highlight maxima (ice > 0.5 μm and WVap, respectively) in opposing parts of the emitted plumes
=> implies a limited uncertainty in WVap m'nt for DC-8 in Sierra Nevada UTLS



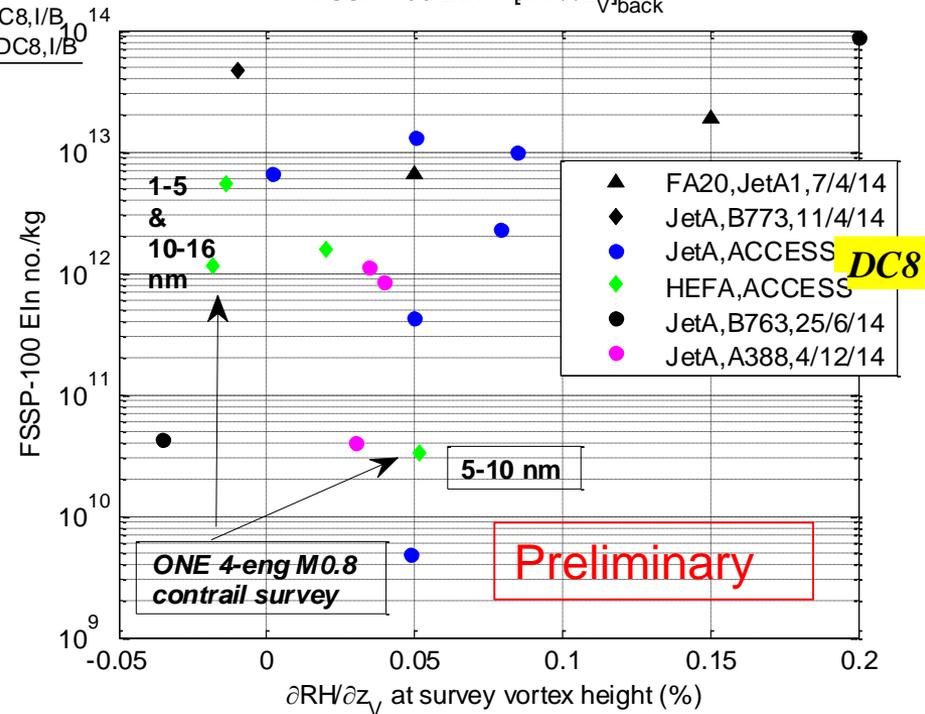
FFSP-100 EIn, environmental parametric variation:-

– With *local* background atmosphere, RH_w , RH_i , T_s , $\partial RH_w / \partial z$, CN

FSSP-100 EIn $\sim RH_{back}$

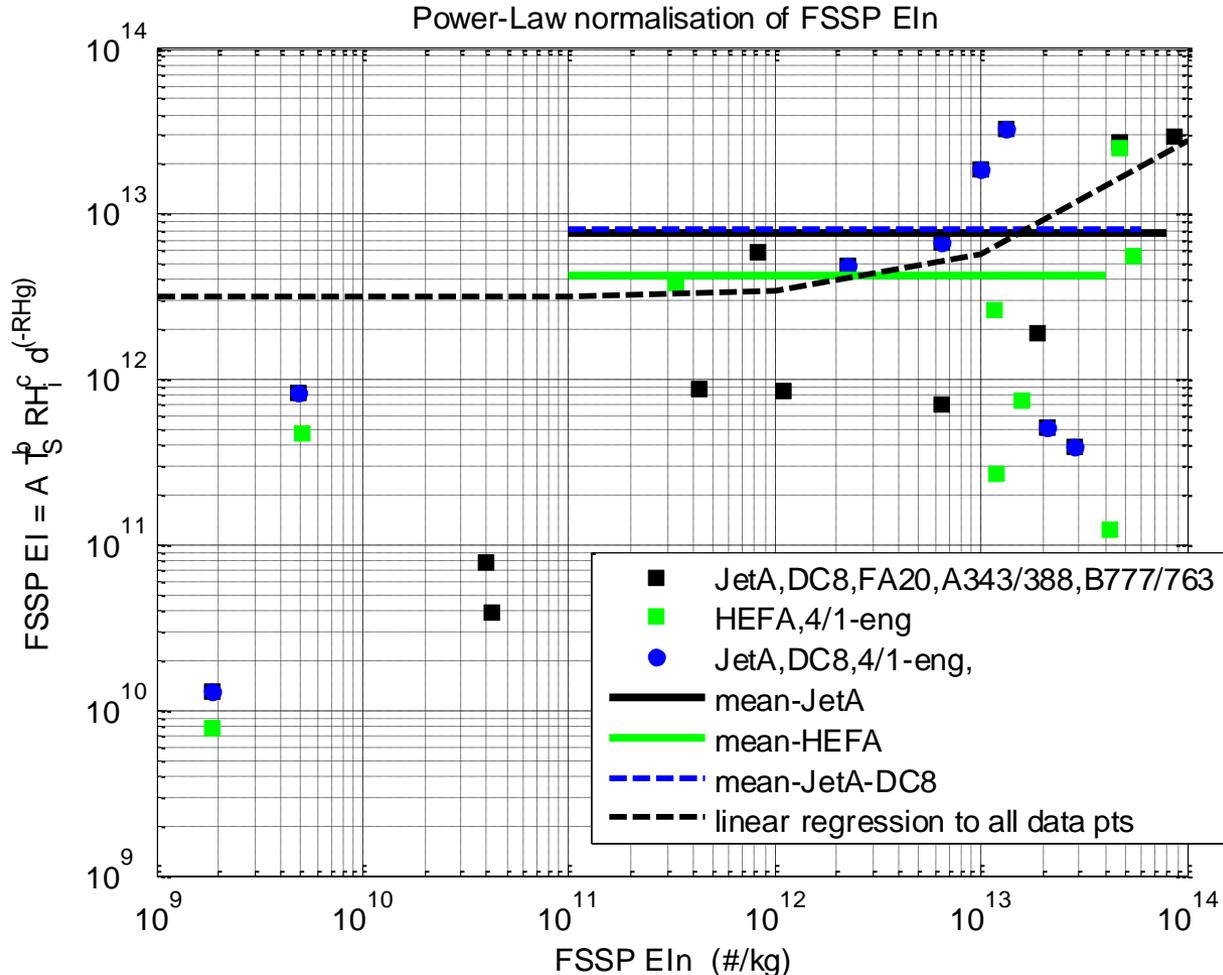


FSSP-100 EIn $\sim [\partial RH / \partial z]_{V_{back}}$



FSSP-100 Ice EIn, Power-Law normalisation:-

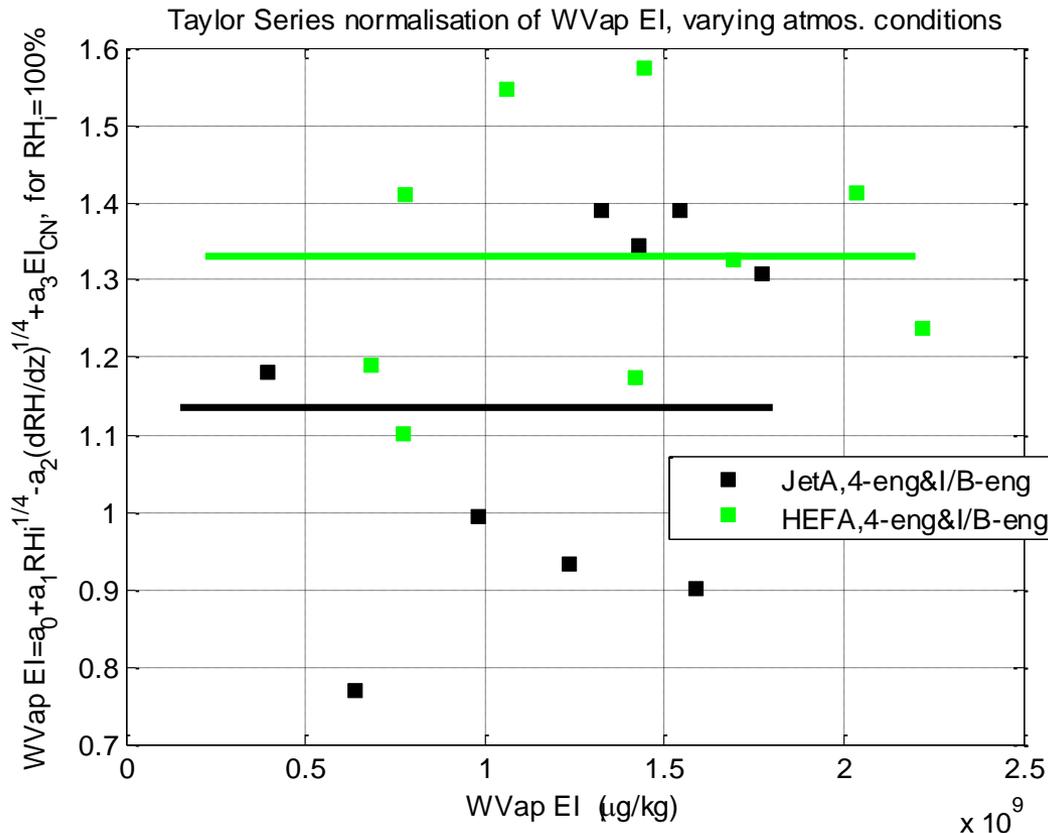
- With *local* background atmosphere, RH_i , T_s , $\partial RH_w / \partial z$
- for a relation $EIn = A T_s^b RH_i^c d^{(-\partial RH_w / \partial z)}$ – use an error minimisation parameter-model estimator (Matlab®) for A, b, c & d estimation



- Thus, corrects for changes in these background environmental conditions:-
- suggests a 47% reduction in ice $>0.5\mu m$ EIn, but this is $<\sigma$, for HEFA blend *c.f.* JetA for DC-8/CFM-56, MaxEff, For the wake vortex-dominated DC8 contrail

Water Vapour measured EI:-

- Combining integrated Wvap plumes, for 4-eng & I/B 1-eng
- Taylor series i/d for T_s , RH_i , $\partial RH_w/\partial z$, CN_EI (similar par.I/D as ice part.)
- then normalised to 223 K, 100% RH_i , avg RH gradient & actual CN-EI:-
Suggests 20% (1σ) increase in Wvap for HEFA50% *c.f.* JetA low sulphur



- Higher Wvap EI \equiv lower IW EI
(however experimental σ quite large)

- thus, this model is consistent with the FSSP ice EI_n

CONCLUSIONS & future work:-

NRC T33 ACCESS II emissions data, measured holistically across 4-eng emission plumes at M0.8 & 1-eng plumes at M0.52;

- aerosols, bulk CN ≥ 10 nm (7610 CNC)
 - 57% reduction in EI from JetA to HEFA blend, which is 4σ , for a data-set standard deviation, σ , of 13%
 - NO_y (Thermo 42I) measured NO EI values in the range 3-15 g/kg (MW, 46), increasing with engine temp (thrust), with an overall data-set σ of 29%
 - CO₂ (Licor 840A), EI derived independently (using holistic plume integration)
 - Successful estimation of CO₂ EI, mean EI of 3.26 kg/kg, with σ of 11%
 - Contrail microphysics (0.2-30 km), when normalised using power-law or Taylor series functions for variations in background T_s, RH, RHi, RH lapse rate
 - ≥ 0.5 μ m ice particle EI reduction of 47%, but that is $< \frac{1}{2} \sigma$
 - Water vapour EI increase of 20% from JetA to HEFA blend, but σ also 20%
 - CONCLUDE:- Other than CN, the JetA to HEFA comparisons all are of the order, or less, than experimental error, therefore they are not, as yet statistically relevant
 - Thus further HEFA & other alternative fuels emissions flight data is warranted.
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QUESTIONS?

